Technology Report

POTENTIAL APPLICATION OF NONDESTRUCTIVE TESTING METHODOLOGIES UTILIZED IN OTHER INDUSTRIES FOR PIPELINES

Contract DTPH56-05-T-0003

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July, 2006

Statement

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1. EXECUTIVE SUMMARY

As a consequence of Integrity Management rulemakings, the pipeline industry has made major technical advances in the use of nondestructive examination (NDE) technologies to improve the quality of in-line inspections. To ensure proper direction of on-going research and development (R&D) efforts in this area, PHMSA commissioned this study with the specific objective of gathering and reviewing information on existing, new and developing technologies used in industries outside of the pipeline industry to determine if their nondestructive examination (NDE) solutions would be suitable for the evaluation of gas and oil transmission pipelines. Where a potential for technology transfer and/or synergies exist, suggestions on which developments might provide priority value to the pipeline industry are provided.

The investigation was conducted primarily through literature searches, meetings with other industries' NDE experts, and discussions of proceedings of recent meetings. It was determined that there are no new breakthroughs or emerging technologies that could be adopted for use in the pipeline industry at this time. However, as a result of the study, a series of specific recommendations, by technology, are made and comments or references are included on recent developments of note in the pipeline industry. In general:

- It is recommended that pipeline NDE subject matter experts meet with their counterparts in the nuclear industry on a periodic basis. There are a number of issues the nuclear industry is addressing that are of significant interest to pipelines, such as inspection of stress corrosion cracking (SCC) in piping. (Such an effort was initiated four years ago but was dropped due to pipeline industry R&D reorganizations.)

- It is recommended that the In-Line Inspection (ILI) Systems Qualification standards issued last year be incorporated into the Integrity Management Program regulations so that both service providers and operators utilize the standards to obtain consistent and verifiable ILI results with increasing reliability.

Although the physics of the processes used to obtain datasets from inspections have not changed, in recent years, tool resolution and analytical techniques have progressed significantly. There is previously undetected information within recorded indications, and analyses must extend beyond simple interpretations of signal magnitude and direction. Additional, future efforts should focus on data reduction, spectral, phase, and other analyses to improve accuracy, and the statistical evaluation of data. There are significant advances that can be made in these areas, and this work should be conducted in parallel with the pursuit of new or improved NDE technologies.

2. INTRODUCTION

The objective of the work resulting in this report is to review and help ensure efficient transfer of technology from the nuclear, ship building, pressure vessel and large structures industries into the pipeline integrity services sector to provide increased safety of the nations' pipeline infrastructure. To this end, this report describes the various available technologies and comments on their suitability to detect and characterize anomalies before they become defects in pipelines requiring immediate or scheduled repairs. The report summarizes current research efforts, recommends technology transfer, suggests hybrid technologies and where appropriate, identifies suitable experienced R&D professionals in other industries who can help develop prototypes for the in-line inspection (ILI) of energy pipelines.

The latest status of advances in nondestructive evaluation (NDE) in the pipeline industry was obtained through participation in several pipeline industry meetings. Combining that knowledge with literature searches and one on one dialogue with other industries' experts, has enabled L&A to recommend some actions and achieve the objective of this work.

There have been significant advances in pipeline NDE development in the past 4-5 years, brought about by the industry's need to meet Integrity Management regulations. Two ILI areas that still demand more effective solutions are:

1. identifying and discriminating simple dents from complex dents with gouges and cracks;
2. inspecting gas pipelines to identify stress corrosion cracking (SCC) and more effectively characterizing the SCC threat in both liquid and gas pipelines based on ILI assessments.

In addition to these, reliable in-the-ditch determination of crack depths, particularly for evaluation of SCC colonies is needed.

Our investigations in the pipeline industry also indicated a need to better understand the processing and interpretation of inspection data after it is collected. The large uncertainties and relatively low confidence levels presently quoted for ILI inspections coupled with the inaccuracies of in-the-ditch measurements and some inaccuracies in proper defect type identification, leads us to conclude that this area is one that can realize significant improvements especially through process consistency. This topic is also discussed herein.

3. APPLICABLE TECHNOLOGIES

A review of other industries, especially the nuclear industry, did not uncover any radically new technology that has not already been considered and tried by operators and service providers in the pipeline industry. Technology transfer across industries is already a normal occurrence, and to some extent, this comes through the pipeline industry service providers that support customers across multiple industries. Consequently, technologies that the pipeline industry uses and is presently developing are consistent with activities underway in other industries.

In many cases the ILI service providers now offer multiple inspection technologies on a single tool body to improve data integration and minimize service interruptions. The most familiar combination is a high resolution magnetic flux leakage (MFL) tool combined with inertial guidance to "map" the pipeline both for wall loss and in three dimensional space[1]. Several of the MFL tools now combine caliper technology on their sensor arms to obtain the internal diameter (ID) ovality for subsequent localized stress evaluation, thereby increasing the value of an inspection run[2].

Tools and potentially employable technologies that were reviewed in this study are:

- Magnetic
    - Magnetic Flux Leakage especially improved signal processing
    - Remote Field Eddy Current Inspection (RFEC)
- Ultrasonic
    - Gas Coupled UT
    - Phased Array Ultrasonic Inspections (PAULI)
    - Guided Wave UT
    - Electromagnetic Acoustic Transmission (EMAT)
- Visual Inspections

All of the technologies are available as manual units, some have computer driven systems to scan areas, and a number of these are available on-board ILI platforms. Several, however, are still in the laboratory developmental stages such as the gas coupled UT and some of the remote field eddy current tools for robotic pigging.

4. Discussion

MAGNETIC FLUX LEAKAGE

Magnetic flux leakage (MFL) ILI tools are the most prevalent inspection method utilized in the pipeline industry, especially for metal loss inspections, such as external and internal corrosion. There have been and continue to be significant developments in MFL tools for piping inspections.

The principle of operation of MFL metal loss tools is based on the fact that ferromagnetic materials such as steel will carry up to 1000 times as much magnetic flux as air or liquid under the influence of an applied magnetic field. When the steel is magnetically saturated and there is a reduced cross section in the wall, some flux leaks into the airspace around the steel creating a leakage field proportional to the reduction in wall thickness. It is the detection of this leakage field that enables the MFL tool to identify a loss of steel from the pipe wall such as that associated with corrosion or other metal loss anomalies (See Fig. 1).

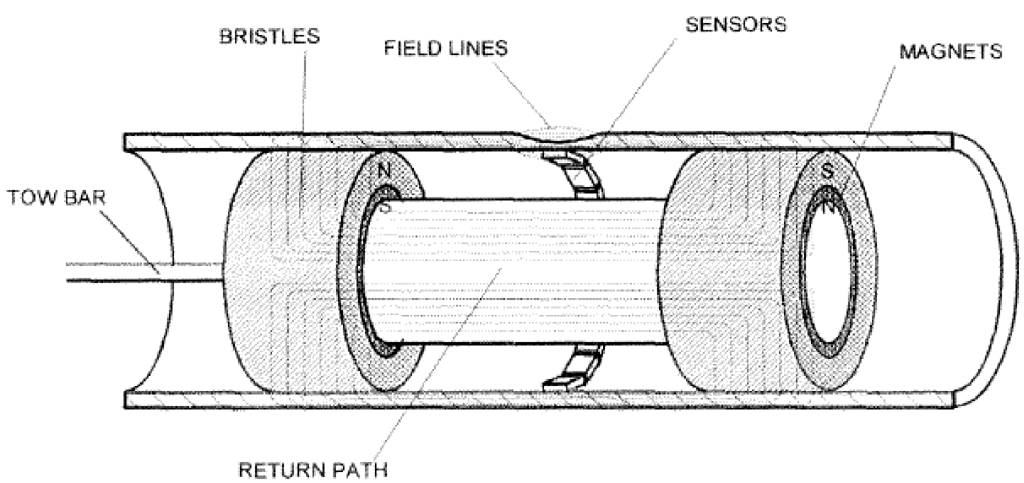

Fig. 1 Representation of a Magnetic Module of an MFL Tool (Axial Field) [3]

MFL tools have evolved from "standard" resolution to "high" resolution. The tool resolution determines the dimensions of the smallest feature that can be detected and sized. High resolution tools typically have many more, smaller sensors spaced tightly around the perimeter of the tool to better detect and size small features or anomalies. In-line inspection tools, termed "pigs", originally included only single sensor technologies, either a caliper, MFL, Ultrasonic, transverse MFL, or geo-referencing inertial guidance (mapping) tools. Multiple inspections required multiple runs to obtain the variety of datasets, forcing the operator to address the complexities of detailed data integration, which layers images, one inspection over another, and on top of the system facilities maps. Data integration allows the easier recognition of correlations to identify and better characterize problematic locations. Today, ILI tools have become multifunctional, combining MFL, geometry and pipeline mapping tools into a single run to avoid such complexities and enable cost-effective data collection.

The flux leakage signals produced by the presence of dents are challenging because they are not always the result of simple metal loss or deformation. Pipe wall geometry changes associated with dents cause sensor lift-off and signal inaccuracies, while work hardening of the steel and possible metal loss due to gouging or the presence of cracks within the dents all generate changes in the magnitude, direction and shape of the flux leakage signals. Recent developments in MFL have been aimed at incorporating caliper pig technologies in making MFL a more robust tool that can simultaneously detect, characterize and size dents. Adams[4] and Brown[8] describe a multi-purpose tool that measures wall loss, geometry and inertial measurement. The geometry feature uses both touchless, electronic distance measurement and mechanical arms for dent characterization.

Appendix F lists the inspection work Battelle Columbus conducted for the Pipeline Research Council International, Inc. (PRCI) to find mechanical damage. PRCI's present efforts are focused on further development of dual magnetization tools and on evaluating the performance of existing MFL tools for mechanical damage location, discrimination and characterization. For the dual field tool, which includes high resolution MFL where the pipe wall is magnetically saturated and a second set of detectors requiring a much lower magnetic field saturation, both the direction and magnitude of the signal change representative of a work hardening signal can be separated. These existing efforts to detect, characterize and size dents and dents with stress risers such as gouges and cracks continue to receive commercialization support from both operators and service providers. An example of this is a recent article in Pipeline and Gas Technology by J.C. Simek that describes the work Enduro Pipeline Services has completed to date using high and low magnetization MFL[4]. The article describes the work on "second quadrant" MFL, the quadrants referred to are from MFL hysteresis curves. PRCI plans to work with one ILI vendor to accelerate the commercialization of this technology.

To date, these magnetic tools have not been successful locating smaller cracks. Not only must the magnetic field be at right angles to the crack, but there must be a reasonable air gap at the crack face to allow flux leakage. Tight cracks are practically invisible as little of the magnetic field is forced out of the pipe wall. MFL tools generally apply the magnetic field in the axial direction as shown in Fig. 1, so girth oriented cracks are more detectable. Axial cracks are essentially invisible and a transverse field tool (transverse flux leakage, TFL) is required to attempt the location of SCC and long seam cracks.

REMOTE FIELD EDDY CURRENT INSPECTION (RFEC)

Remote-Field Eddy Current (RFEC) inspection is a nondestructive examination technique suitable for evaluation of the ID and outside diameter (OD) of conducting, tubular goods from the inside using a probe placed near the inner surface. Because RFEC involves transmission of eddy currents through the wall thickness of the tubular, the technique effectively provides a through wall examination using only the interior probe. One advantage of RFEC inspection is that the probe can be made more flexible than saturation coils, conventional eddy current, or magnetic probes, thus facilitating the examination of tubes with bends and diameter changes. It is also approximately equal in sensitivity to tools currently used in the industry to locate and identify axially and circumferentially oriented flaws in ferromagnetic materials. Current, substantial research efforts on RFEC are aimed at establishing its effectiveness for robotic ILI inspection, with an emphasis on unpiggable gas pipelines [5&6].

RFEC is an accepted, mature inspection technology suitable for the evaluation of wall loss in a number of applications (e.g., boiler tubes in power generation facilities). In a tubular geometry, such as that shown in Fig. 2, an axis-encircling exciter coil generates eddy currents in the circumferential direction. The tubular geometry allows the induced eddy currents to rapidly cancel the magnetic field from the exciter coil inside the tube, but does not shield the magnetic field from the eddy currents that are generated on the outer surface of the tube as efficiently. Consequently, two sources of magnetic flux are created in the tube interior: the primary source, from the coil itself, and the secondary source from eddy currents generated in the pipe wall. The electromagnetic skin effect causes the density of eddy currents to decrease with distance into the wall of the conducting tube; however, at typical nondestructive examination frequencies, substantial current density is produced at the outer wall. At interior locations near the exciter coil, flux generated by the coil is dominant, but at larger distances, the eddy currents generated in the pipe wall dominate. A sensor placed in this second, or remote field region measures flux from currents through the pipe wall. The magnitude and phase of the signal received by receiver coils depends on the wall thickness, magnetic permeability and electrical conductivity of the tube material, and hence, changes in the received signal can be used to detect the presence of discontinuities in the pipe wall (ASM Handbook – Volume 17 [5]).

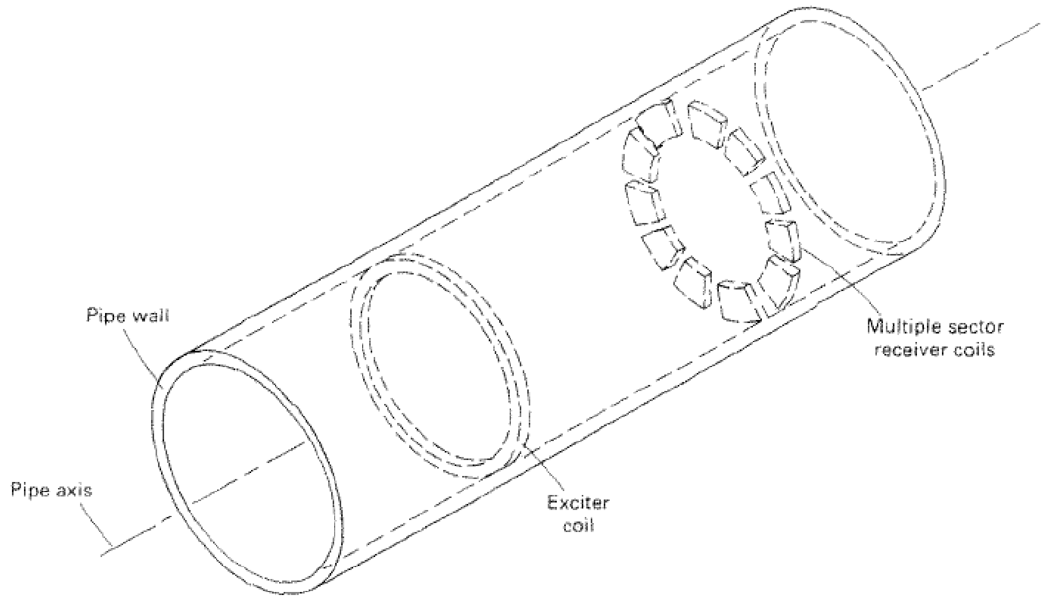

Fig. 2 RFEC with exciter coil and multiple receiver coils[5]

In an effort to ensure integrity of the nation's gas distribution network, PHMSA and the gas distribution industry have drafted a Distribution Integrity Management Program (DIMP) with integrity assurance criteria similar to that developed for gas transmission lines. Regarding integrity assessments, most gas distribution mains are not piggable for a variety of constraint and physics complications (e.g., physical layout and size of piping). To help address this situation, PHMSA has supported two substantial research efforts:

1. development of a self propelled robot that can move through distribution mains and,
2. an effort to develop a nondestructive examination technique that will be compatible with the robot and enable inspection of distribution mains.

Southwest Research Institute (SwRI) and the Gas Technology Institute (GTI) are both developing RFEC systems for that purpose [6].

SwRI's technical approach is to use RFEC with expandable exciter coils to accommodate different diameters of pipe in the same run. They are also pursuing the development of defect characterization methods. To date, SwRI has met the design criteria of the robot and demonstrated an ability to detect and characterize metal loss defects for 6-inch and 8-inch pipes with wall thicknesses typically of that found in the gas distribution network. Further development is required, and based on the demonstrated effectiveness of their approach, this project should continue to receive support.

ULTRASONICS

The ultrasonic inspection technique has been much more successful in measuring wall thickness and is particularly effective in locating cracks. Historically, piezoelectric crystals such as quartz were used as ultrasonic transducer (UT) materials. A major challenge associated with conventional ultrasonic techniques is the requirement that the piezoelectric transducers be acoustically coupled to the material to be evaluated with an acoustical impedance matching coupling medium such as water, oil or grease. Coupling is generally not an issue for oil pipelines that contain fluids which are acoustically conductive and adapt well to the use of UT sensors onboard ILI tools. Past usage of UT technologies on these pipelines shows that sound is relatively efficiently conducted into and out of the pipe wall. Normal beam probes easily provide ovality profiles and are able to effectively measure widely varying remaining wall thickness in defect areas such as those associated with many types of corrosion. Similarly, angle beam probes using multi-skip "pitch and catch" paths will scan for crack like features, especially around welds or for SCC. These tools can also detect dormant mill defects, and other technologies can be used to focus the ultrasonic beam to inspect a single weld volume such as just the root pass.

Despite many positive attributes, gas pipelines remain difficult to inspect with ultrasonic techniques. At higher gas transmission pressures, methane begins to act more as a fluid. Moreover, there has been limited success using normal beam UT to measure ovality and wall thickness in these lines. The very large index of refraction in methane makes angle beam techniques extremely difficult to employ effectively. British Gas developed a sensor that placed angled ultrasonic probes inside fluid filled rubber wheels to enable coupling through the fluid, wheel tread, into and out of the pipe. This technology is still available from GE-PII, however, operators have not been fully convinced of its reliability since sound transfer is complicated by interfaces and internal surface conditions that can increase signal loss.

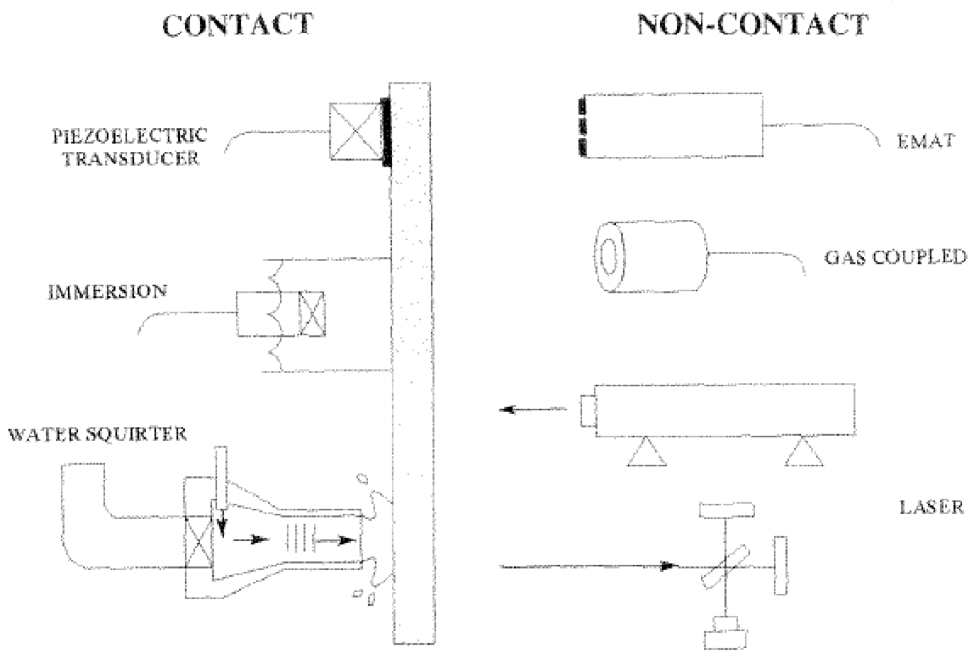

Figure 3 Contact vs. Non Contact Ultrasonic Systems [7]

A method of non-contact generation and detection of ultrasound is of practical importance and several such techniques are presently available in various stages of development. Fig. 3 shows various contact and non-contact ultrasonic techniques. The electromagnetic acoustic transducer technique (EMAT) avoids the contact problem in gas lines by using electromagnetic coupling to transfer sound energy across a small "air" gap. The sensor contains a strong permanent magnet field and superimposes an electromagnetic field with a coil and appropriate circuitry. The coil pulses the magnetic field and induces displacement, and hence, sound into the surface of the steel pipe. The sound pulse travels through the pipe wall and returns, distorting the pipe surface, which is sensed by the same and/or another coil and electronically magnified. Time of flight is measured and inference about the sound path are interpreted as in conventional piezoelectric UT techniques. Increasing the "lift off" or the "air" gap distance between the coil and the pipe surface severely deteriorates the sensitivity of the EMAT technique.

The Laser pulse works to rapidly heat and expand the pipe surface, generating sound in the pipe. Optical Interferometry techniques are used to sense the returning sound pulse as shown in the diagram. In many cases, an EMAT or other sensor must be combined with the laser to detect the return signal from a polished surface. Since a deteriorated surface has roughness, the optical technique becomes difficult to employ reliably. Similarly, different combinations of the source and detection technologies in Fig. 3 have been attempted to improve detection, characterization, and inspection quality.

A significant issue for pipelines is the correct and relatively accurate detection, characterization and sizing of cracks such as those that maybe associated with welds or stress corrosion cracking (SCC). Cracks remain notoriously difficult to size to any reasonable accuracy in natural gas pipelines, and as such, the Codes and Regulations generally mandate pipe cut outs and replacement with new pipe if significant cracks are detected. The new ultrasonic tools in liquid lines can size and generally permit the prioritization of cracks into immediate versus scheduled responses.

High resolution magnetic flux leakage (MFL) ILI tools can, to some extent, detect cracks occurring at right angles to the flux field (e.g., girth weld cracks), and with transverse flux leakage fields (TFL), detect long seam cracks, and in some cases, SCC colonies. However, there is industry consensus that ultrasonic inspection is the better method for crack detection and sizing, depending on crack size and orientation [8&9]. Reference 8 describes Enbridges' extensive field work in detecting and characterizing SCC with UT ILI tools. They conclude that further work is required to more effectively characterize SCC, even with the current success of the UT ILI tool in finding SCC. In Reference 9, an external automated pipe scanner is used "in-the-ditch" for characterizing the extent of wall loss, and FAST (Flaw Analysis & Sizing Technique) was adapted to use a 70 degree angle beam UT transducer. This tool is recommended for long seam crack detection and sizing for in-the-ditch inspections. It had limited success for SCC detection and sizing, as the large number of cracks in the SCC colony made it very difficult to determine any crack depths. Similar services are available and are discussed in the following sections.

As stated previously, UT ILI tools are consistently and effectively used in liquid pipelines [10, 11 &12] as the liquid product is the convenient coupling medium. For gas pipelines, the coupling must surround the UT-ILI tool. Generally the UT-ILI pig must be run in the center of a pig train with the tool moving inside a slug of water to ensure sound transfer into and out of the steel pipe wall. These UT ILI tools detect the sound reflected by the ID and OD surfaces of the pipe wall. Wall thickness and corrosion are easily determined by time of flight measurements. Crack detection requires the UT signal to bounce or "skip" alternately off the ID and OD walls as it travels part way around the pipe. Reflections back to the source sensor from planes like cracks and/or signal loss at the receiver can indicate the presence of a crack. The steel cleanliness, skip geometry such as a simple change in wall thickness or a dent will change the path between the source (pitch) and detector (catch) and make the tool ineffective. Liquid filled wheeled probes have had limited success in gas transmission lines. The sound transfer is more difficult since there are more interfaces and internal surface conditions can increase signal loss.

There is clearly a need to improve the gas transmission pipeline industry's ability to solve the sound transfer coupling issue and be able to reliably detect and begin to size cracking and most specifically work to characterizing the SCC threat. Several potential alternative technical solutions to piezoelectric UT are discussed here.

EMAT – ELECTOMAGNETIC ACOUSTIC TRANSDUCERS

EMAT provides a strong static magnetic field and superimposes an alternating electric field into the article to be evaluated. This results in a Lorentz force acting on the material that generates sound waves which can travel long distances. EMAT inherently induces horizontally polarized shear waves, while conventional UT induces vertically polarized waves. Horizontal waves lose less energy at interfaces and travel longer distances, but vertical waves are much better for sizing anomalies At the receiving end, these sound waves, in combination with the magnetic field, induce electrical impedance in a coil that can be measured to provide information about the article and the ultrasonic signal. Unlike piezoelectric induced UT, EMAT ultrasonic testing is a non-contact technique and operates across a small air gap. However, the AC coupling effectiveness is reduced by increased lift-off or greater coil-to-pipe surface distances. (See Fig. 4)

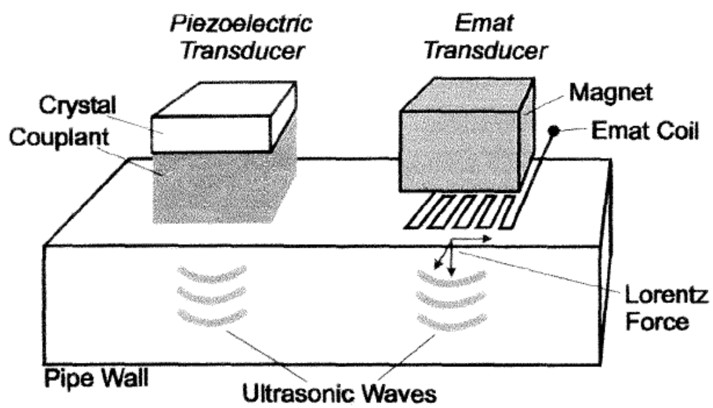

Fig. 4 Piezoelectric & EMAT Transducers[13]

The pipeline industry has made significant strides in the development of ILI tools using EMAT, especially in detecting and characterizing SCC in gas pipelines [14]. The paper titled "Validation of EMAT In-Line Inspection Technology for SCC Management" by M. Kothari, U. Strohmeier, N. Ronsky, S. Tappert, J. Larios (IPC04-0078) describes the results TransCanada obtained with a commercial ILI EMAT tool in a gas pipeline inspection[15]. The inspection tool uses shear waves, Rayleigh waves and transverse shear (TS) or 0 deg. waves. Results of the study indicated that:

- Actual axial and through wall depth measurements correlated well with predicted measures for features identified correctly as SCC colonies.
- An overall probability of detection (POD) value of 92% was determined. The EmatScan* CD system showed a 46% true positive rate for probability of identification (POI) in the 2 mm to 5 mm feature depth range. The EmatScan* inspection data was compared with a previous UltraScan* CD inspection showing good correlation.
- A section of the run length was hydrostatic tested after the inspection with no test breaks occurring." This confirms that no significant cracks were missed.

* Copyright – General Electric (GE) Inspection Services

- From an SCC integrity management perspective, the EMAT tool is currently not an alternative to hydrostatic testing. However, refinements to the tool hardware and software will lead to improvements in tool robustness and discrimination performance.[8]

Appendix E reproduces a brochure from one service provider describing their EMAT crack detection tool.

EMAT holds great promise as a solution for detecting, sizing and characterizing SCC in gas pipelines [16]. Development is progressing for this much needed application. The work TransCanada and GE Inspection Services reported in 2004 is laudable and the technique is clearly achieving promising results for one operator's unique conditions. An industry initiative to validate the EMAT system for more general use would be highly desirable. It is also possible that the EMAT tool, for various reasons, may never fully achieve the results required to be an effective SCC integrity management tool and replace the well proven hydrostatic testing methodology for ,managing the integrity of natural gas pipelines for the SCC threat. The industry should continue to support alternative development efforts such as those described in this report.

AIR (GAS) COUPLED UT

High pressure gas conducts sound but not as effectively as water or petroleum products. Research and development (R&D) work on air coupled UT has been conducted over a number of years in different industries [17 to 21]. The gas pipeline industry also sponsored research on this technique at the Southwest Research Institute (SwRI) [17], but that work was moved to GTI before a pre-commercial success had been reached. Gas coupled UT is well known as an internal ILI geometry tool, and work is continuing in this area under PRCI and DOE sponsorship at GTI. UT normal beams were originally used to center inertial guidance tools in the pipe, and later used to locate and profile pipe ovality and dents for localized strain analyses. Since the index of refraction is so great between the gas and the steel, alignment of the UT probes is critical for accurate detection of the OD wall reflection. These tools have been successfully demonstrated in liquids pipelines, but to date, have shown limited success in gas transmission lines.

Schramm & Fortunko[17] describe work conducted at SwRI, supported by GTI & NIST. Normal beam experiments were conducted in a static environment and proved the possibility of using 1000 psi gas as the couplant. The basic principle behind this work is to use the normal beam to detect the ends of SCC cracks as they grow from the OD into the pipe. Significant, further work is needed to prove the usefulness of this approach, which would be limited to higher pressure pipelines. There are other, more promising approaches to consider.

The rail industry has supported the development of laser-generated ultrasound for rail inspections [22 to 25]. Fig. 5 depicts the setup for a pulsed laser-generated signal and a UT (variable capacitance detection) inspection for rails[18].

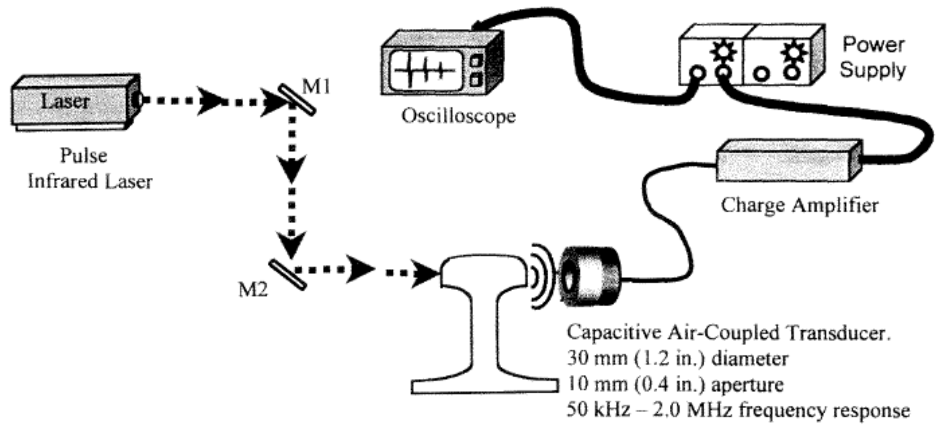

Figure 5 - Laser generation and air coupled detection experimental setup[19].

The generation pulse travels through a set of mirrors (M1 and M2 in the figure), and the detection beam travels through the air to the capacitive air coupled transducer assembly. The air coupled transducer operates with a 10 mm (0.42 in) aperture and lift-off distance exceeding 0.1 m (4 inches).

The significant benefit for rail systems and also gas transmission pipelines is that neither the transmitting nor receiving signal requires contact or couplant. McNamara avoids the low signal-to-noise ratios experienced by non-contact ultrasonic methods by employing discrete wavelet transforms to obtain useable signals[22]. "When compared to the traditional Fourier transform procedures that lose the time resolution of non-stationary signals, wavelet transforms retain both the time and the frequency resolution. McNamara[22] concludes that "discrete wavelet transform emerges as a powerful tool to ease the transition to the field of non-contact ultrasonic rail testing". This type of signal detection and analysis is directly applicable to gas coupled UT technologies. The current gas coupled UT tool service providers might be encouraged to explore wavelet transforms as a means to extract information out of current signals.

ILI service providers best understand the adverse conditions found in gas pipelines that may limit the usefulness of optics and require an alternative approach for detection such as EMAT. Reportedly, one of the pipeline inspection companies is working on a gas coupled UT ILI tool for wall thickness determination that may become commercial in 2007.

Rail inspections bear many similarities to pipeline inspections. Railcars outfitted for rail testing run on the tracks at fairly high speeds to assess long distances in an "inspection run"[24]. The contact methods presently used, using water sprays as a couplant, have a number of disadvantages, including lack of full coverage of the rail geometry, and the rail way industry has therefore been supporting alternate inspection methods to look for cracks, particularly in the railhead flange. The combination of laser generated ultrasound and UT transducer detection setup, along with the discrete wavelet transform method of data filtering, should be investigated for potential use in gas pipelines for crack detection and sizing[26].

TIME OF FLIGHT DIFFRACTION (TOFD)

One of the UT methods being explored by the nuclear industry to detect Intergranular Stress Corrosion Cracking (IGSCC) is the Time of Flight Diffraction Back Scattering technique. (TOFD). Attachment A includes an excerpt from a presentation given by a leading expert in this field to the Nuclear NDE group last year. PRCI has also investigated this technology for the detection of root and other welding defects, wherein the inspection is conducted as soon as practicable after the cap weld is made (usually three to six joints behind the cap pass crew) [27]. Experimental work to determine the effectiveness of this approach for in-the-ditch measurements of SCC has also been investigated with little success reported[28 - 30]. If this method can be proven effective, it might be possible to develop an EMAT or water coupled system for installation on ILI tools for the detection and characterization of SCC in gas pipelines [20, 21 & 22].

PHASED ARRAYS

Major improvements in UT inspections have been made in the area of Phased Array ULtrasonic Inspections, known in the NDE industry as PAULI [31]. Song's development of an ultrasonic phased array system for nondestructive tests of nuclear power plant components describes such a system, a modified medical system to handle industrial components[31,33&38]. In addition, notes from nuclear industry work conducted by Wesdyne of Westinghouse Nuclear Company, describe their R&D efforts for nuclear components. (See appendix B).

UT inspections with automated raster scanning devices are now common on pipelines for both circumferential weld inspection and in-the-ditch anomaly inspections, especially when combined with TOFD [32 & 33]. Several vendors now offer phased array inspection systems for these applications. (See attachment C.)

Phased array systems are just beginning to be utilized for pigging inspection for liquid lines.. Phased arrays may have 64 or 128 UT sensors that are "fired" sequentially, and the consequent return signals measured sequentially.

Phased arrays require the same acoustic coupling required for standard UT, and therefore, they do not solve the problems for in-service inspection of gas pipelines. Their dominant use in the pipeline industry should be for characterizing and sizing SCC in-the-ditch. Development work to improve and quantify the efficacy of phased array for SCC characterization and sizing should be continued [30].

ULTRASONIC GUIDED WAVES

The basics of guided waves are given in reference [34]. Rayleigh and lamb waves from ultrasonic transducers can be used to interrogate long lengths of pipe. As stated in the reference, "the main attraction of long range guided wave testing is that it enables a large area of structures to be tested from a single transducer position, thereby avoiding the time consuming scanning required by conventional ultrasonic or eddy current methods." Specifically for pipelines, longer lengths of inaccessible pipe, such as through walls and under road crossings can be inspected. (See appendix D for a commercial application for pipelines.) Guided waves can detect welds and anomalies, such as corrosion, but typically cannot size them nor determine if they are on the ID or OD of the pipe. Vendors are claiming that they can, in some instances, begin to size the anomalies. The pipeline industry, and particularly the Northeast Gas Association, (NGA), have been conducting trials for LDCs with PHMSA support to conclusively prove the capability and substantiate such claims. Further work is underway at NGA to solidify the ability to identify and characterize defects over some distance using guided waves.

GTI and the American Gas Association (AGA) have just completed a joint industry program (JIP) for external and internal corrosion direct assessment with GUL WaveMaker III technology[35]. GTI recently received PHMSA R&D support to continue this work on guided waves for pipeline applications. It is expected that the completed AGA/GTI JIP results may become available to the general public in early 2007. The PRCI is also pursuing a study to evaluate the effectiveness of GUL for sizing axially oriented, long narrow anomalies.

The technology can find reflectors and determine if they are welds or wall loss [36 &37]. The soil and coating determine the range upstream and downstream from the tool location. In casings, up to five joints (or 200 ft) have be inspected, but in soils and particularly with coal tar coatings on the pipe, it is difficult to inspect more than a joint and a half (40 to 60 feet) away from the tool. More powerful pulses and better software analysis techniques have made small improvements. In general, if the reflector exceeds a threshold, the operator needs to be prepared to investigate and then mitigate or repair. If the threshold is not exceeded, the pipe segment can be considered a monitored segment until the next scheduled integrity assessment. The technology is easily oversold, but has been effective in screening defects to provide a simple go/no-go decision for short pipe segments.

The primary purpose for guided waves is to evaluate inaccessible pipe and the most difficult defect to characterize and size, SCC [38-40]. Pipelines crossing under interstate highways and rivers such as the Mississippi are difficult to inspect locations that are yet to be completely inspected over long distances. Professor J.L. Rose [41], whose work was extensively sponsored by the pipeline industry, optimistically states: "Even though much information can be found in the literature on guided waves, the following presents the <u>expected</u> benefits of guided wave testing:

- testing over long distances from a single probe position

- establishing appropriate wave resonances and excellent overall discontinuity detection and sizing potential through proper mode and frequency selection or tuning
- the frequent acquisition of higher sensitivity than that obtained in standard normal beam ultrasonic testing or other NDT techniques
- the ability to test structures underwater, coatings, underground or insulated structures, multilayer structures or concrete with excellent sensitivity
- cost effectiveness made possible because of testing simplicity and speed (often less than 1/20th of the cost of standard normal beam ultrasonic and other testing techniques)
- easy implementation of leave in place sensor application for wide area testing.

The significant advantage of this technique is the ability to inspect inaccessible piping, which warrants further research to achieve the goal of characterizing and sizing defects reliably in inaccessible piping [40]. Once commercial units are available, they should be evaluated to ensure that they produce the same quality expected for ILI tools as set out in API 1163.

VISUAL INSPECTION

Visual observation is the initial inspection technique conducted when the pipe has been excavated and exposed for inspection. Magnetic particle inspection is generally used to characterize cracking from SCC, fatigue, mechanical damage in dents, MIC related cracking in corrosion pits, etc. In many cases, determination of the volume lost to corrosion requires the tedious and meticulous use of micrometers and a bridging bar to map depths over the corrosion grid. Robotic techniques have been developed to perform this type of inspection/measurement quicker and more accurately. Defect depth can be measured in-the-ditch by laser mapping, use of UT with a water or air column[42 & 43], and more recently, a conformable printed circuit based on eddy current[44].

In the nuclear industry, visual examinations are also frequently performed. However, because most of the components to be inspected are contaminated and have high radiation levels, inspections must be conducted under water. Remote TV systems are used for such inspections [45]. A study was undertaken to determine the capabilities of visual testing as performed in the nuclear industry for a number of different plant components [33]. Results of a study on the reliability of visual testing systems related to average Crack Opening Dimensions (CODs) show that the systems may not be able to reliably detect a significant number (often over 50%) of service induced cracks in nuclear components. It should be noted that this study is not directly applicable to pipelines, where remote TV systems are not generally employed for inspections. However, the reported poor detection performance by visual inspection demonstrates that diligence is needed to find tight cracks, especially for threats such as SCC. Round robin studies have also confirmed that highly trained inspectors in an administered test usually miss about half of the deliberately manufactured and hidden problems. A current study or round robin study, similar to the one performed in the Pacific Northwest Laboratories (PNWL) reference and a subsequent recommended practice that industry can use could be beneficial in improving the reliably for "in-the-ditch" inspections to find and characterize pipeline cracking.

DATA PROCESSING & ANALYSIS

In-line inspection of pipelines generates large amounts of data that are normally post-processed and subsequently analyzed offline. ILI data are initially organized and anomalies identified by inspection vendors using algorithms or artificial intelligence screening methods. Human data analysts examine the reduced data set to "make the call", or confirm the presence or absence of defects. Historical review and forensic investigation of inspection logs conducted after a number of reportable incidents showed that defect indications were present, suggesting that indications were either incorrect identifications of defects, unknown or missed calls (i.e., a defect was present and was not interpreted as such). Discussions with a number of the service providers revealed that significant attempts have been made to incorporate artificial intelligence methods to make accurate calls, but found these do not work well for data obtained with MFL tools.

There are emerging approaches to the use of automated data processing techniques that should be considered by the industry [46 & 47]. The final, processed data used for decision making has proven to be a strong function of the methodology used to develop it to that stage. Moreover, it is not unusual for the pipeline operator and the service provider to agree on a "minimum cutoff" below which data is not considered or looked at by a human analyst. Given the typical accuracies, certainties and confidence levels quoted for MFL inspections, for example, +/-10%, 80%, 95%, it is possible that a called 19% through wall anomaly is in actuality a 40% through wall defect that should be considered as a scheduled or monitored repair for a specific reinspection interval. It is also possible that the 40% outlier example could exceed 80% in the interval before the next reinspection activity occurs. In the past, dents were particularly prone to being overlooked through automated data processing. To address this problem, industry-sponsored research could be conducted that would generically address these issues, allowing the service providers to develop their own proprietary solutions unique to their specific tools, so that more marginal indications are correctly identified and then classified for appropriate action. The PRCI is sponsoring research with PHMSA and working with the vendor community to establish, in terms of these metrics, the performance characteristics of MFL ILI with respect to mechanical damage defects.

Statistical analysis of ILI data is another issue that suggests a need for guidance in a consistent industry approach. Many operators may welcome assistance in determining what the appropriate statistical methods are. Surprisingly (after so many years), work has recently been done in this area and the industry should determine what methods are appropriate for ILI inspections as they evolve. While API 1163 addresses some aspects of the identification and characterization issue, more approaches need to be considered. Three references [48 to 50] cover regression modeling and a Bayesian approach to determining Probability of Detection Curves (PODs) [51 & 52]. The combination of these two data initiatives would improve the ultimate quality of reduced data and provide consistency in the application of the reduced data to IMP programs. PRCI is pursuing related research to investigate the performance of MFL ILI techniques for corrosion defect assessment and statistical analysis of collected data sets.

TRAINING AND QUALIFICATION

Several years ago, GTI initiated discussion with the Electric Power Research Institute (EPRI) NDE center regarding technology exchanges on a periodic basis but the program was not pursued. It is strongly recommend that such cross-fertilization discussions be resumed, perhaps with a small group of pipeline industry practitioners such as GTI-OTD, PRCI, ILI Association, and a similar group from the EPRI NDE Steering Committee.

In the '70s and '80s, the nuclear industry encountered NDE problems with eddy current testing of steam generator tubing and detecting and characterizing IGSCC in BWR piping. The EPRI NDE Center was established and its initial mission was to qualify individuals and equipment before they were permitted to perform specific plant inspections. Service providers that wished to perform certain inspections at nuclear plants were required to qualify their crews and equipment on full scale mock-ups at the NDE Center before they could perform those inspections at active plants.

The effort and funding that the nuclear industry spends to address their critical issues is substantial and is by no means recommended or required by the pipeline industry. The concept of proving that a technology or technique is qualified for specific applications is, however, a valuable concept to consider adopting. API 1163, *In-Line Inspection Systems Qualification*[53], provides part of the quality solution. Service providers are required to issue performance specifications for what their inspection tools can provide, which must be supported by statistically valid data. PHMSA should strongly consider incorporating the standard into the regulations by referencing API 1163 in the IMP sections [54] of 49CFR192 and 195. Such an action on PHMSA's part would reduce incorrect or unqualified equipment being suggested or even used for in-line inspections.

The nuclear industry example of a coordinated, industry spearheaded NDE program could be emulated in the pipeline industry without service providers losing their proprietary positions. Since inauguration of the liquid and gas IMP programs, ILI for NDE has become the "backbone" for assessing the integrity of the pipeline

5. CONCLUSIONS

The pipeline industry has made significant strides in improving the nondestructive examination of pipelines over the past four to five years. These improvements include both ILI and in-the-ditch measurements.

A review of recent literature and the practices employed by other industries indicated that further, significant improvements in analysis and other areas can and must be made. Two technical issues that require further development are:

- improved detection and characterization of SCC, especially in gas transmission pipelines, and
- improved capability to detect and correctly characterize dents versus dents with gouges or cracks.

During this review, it became evident that the nondestructive examination of pipelines requires a "systems" approach. While the pigging technologies are important, the industry must improve ILI data reduction and analysis, in-the-ditch characterizations and measurements, as well as the statistical validity of the data.

Improvements in detection, characterization and sizing of anomalies should continue to be stressed in on-going R&D efforts. The review concludes that further analytical improvements can be achieved through automated inspection, the development of innovative data analysis techniques and standardizing the statistical reporting of results.

Section 6 recommends specific activities for each of the technologies discussed.
In several instances, parallel paths are intentionally recommended in an attempt to develop at least one technically competitive capability.

6 .RECOMMENDATIONS

A. Strategic Recommendations: There are some non-technique specific conclusions that were reached as a result of this study.

EPRI's 15th Annual EPRI NDE Issues Meeting Notes of October 2005 [43] lists three issues for nuclear plants that are of interest to pipelines, and conversely, some of the work pipelines have completed that would seem to be of value to nuclear plants.

1. NDE of plastic pipe. Both the gas distribution networks, and the nuclear industry is considering replacing carbon steel A106, Class 3 pipe with HDPE plastic pipe. This is for the non-nuclear side of the plant, cooling water for hydrogen coolers for the generators, etc. Plastic pipe weld NDE is an issue the nuclear industry is working on. It would appear reasonable that the pipeline industry, and specifically the distribution companies, could be of some assistance in this area. PHMSA is already sponsoring an R&D project in this area. The nuclear industry results may be of some help to the pipeline industry.

2. The nuclear industry is working on improvements for remote visual inspections for intergranular stress corrosion cracking (IGSCC). This work may be of some value to the pipeline industry for visual inspections of SCC in-the-ditch. The general subject of NDE for SCC may be a useful area for technology exchange and cost-sharing of R&D activities, and has the potential to benefit both parties.

3. Many nuclear plants have underground piping that may run for hundreds of feet. This piping requires periodic inspection, predominantly for corrosion. The nuclear industry is developing an RFEC capability for this purpose, and the technology exchange of substantial, historical efforts of the piping industry on this topic may provide significant guidance to and support for their efforts.

4. It is strongly recommended that the technology exchange between the nuclear and pipeline industries be reinstituted. The GRI pipeline group and EPRI used to meet annually, and this could again be a periodic exchange, preferably at a mutual or common conference setting such as before a PHMSA-PRCI R&D Forum.

B. Technical Recommendations

MAGNETIC FLUX LEAKAGE

The pipeline industry is the leader in the use of MFL technology based tools. As a result of the IMP regulations, the ILI industry has vigorously responded with continuously improving MFL tool technology. In addition, the pipeline industry has authored several standards, e.g., API 1163 and ASNT ILI PQ, that can be utilized to obtain qualified ILI systems and personnel. The present major shortcoming of MFL is its inability to effectively characterize and size dents and dents with stress risers such as gouges or cracks. Work on dual magnetization tools (MFL with RFEC) may prove successful in discriminating mechanically damaged regions, and support for these efforts should be continued. Combination tools of MFL and geometry should also continue to be further enhanced.

REMOTE FIELD EDDY CURRENT – RFEC

Work underway to develop RFEC for robotic ILI in gas distribution piping should continue. The nuclear industry's use of RFEC for Class 3 piping should be reviewed to determine if there are common interests that could be exploited for mutual benefit.

ULTRASONIC TECHNIQUES

A major issue for the gas pipeline industry continues to be the detection, characterization and sizing of SCC cracks within colonies. Based on available literature and the present state-of-art, non-contact air coupled UT, using laser generated UT input and gas coupled UT or EMAT transducer detection should be pursued vigorously. In conjunction with these, the discrete wavelet transform method of data filtering should be investigated to compensate for the low signal-to-noise ratio of the resulting poor coupling physics of the gas coupled UT system.

The characterization and sizing of SCC is a continuing problem in both the nuclear and pipeline industries. The Time of Flight Diffraction Back Scatter technique is being explored by the nuclear industry. This technique is equally applicable to the pipeline industry and improvements should be explored further, perhaps initially as an "in-the-ditch" measuring tool before it is implemented in ILI tools. Further analysis would be required to determine whether ILI tools could accommodate such a complex technology.

Phased Array Ultrasonic Inspection (PAULI) systems for in-the-ditch measuring of anomalies and for circumferential weld inspections are now being used more frequently. Unfortunately, API 1104, the welding standard for pipelines, does not yet recognize these UT processes and only relies on x-ray based workmanship rules. Industry should work to demonstrate the effectiveness of PAULI and other volumetric inspection systems for these welding applications. In addition, their effectiveness for characterizing and sizing SCC should be assessed and further optimized.

There has been substantial industry support given to long range guided wave ultrasonic (LRUT) inspection systems. There are three commercial systems available, but it is not clear what their true capabilities are for sizing defects or determining if the sound reflecting anomaly is located on the ID or OD of the pipe. Industry should continue to credibly establish the limits of existing systems, and based on those results, support additional development of the guided wave systems for fully inspecting inaccessible pipelines. This work should eventually include the detection, characterization and sizing of all common types of defects that can be found in pipelines. Commercial systems that make detection and sizing claims for certain types of defects should be required to meet API 1163, specifically, to provide statistically proven performance specifications.

ELECTOMAGNETIC ACOUSTIC TRANSDUCERS – EMAT

EMAT has long held significant promise as the non-contact UT methodology that could detect, characterize and size SCC and other types of cracking, especially in gas pipelines. Detection and sizing of SCC remains a difficult NDE issue, and the solution to the problem should not be restricted to one developing technology. It is recommended that full support be given to the EMAT effort, in addition to the gas coupled UT approach outlined above. When commercial, EMAT and/or gas coupled UT systems should be qualified per API 1163.

VISUAL INSPECTION

Based on the results of the study conducted by Pacific Northwest Laboratories on the effectiveness of visual exams as performed in the nuclear industry, the pipeline industry should examine how visual exams are performed and their effectiveness. The industry needs to identify potential enhancements and use or adapt industry guidelines accordingly.

DATA PROCESSING & ANALYSIS

Automated processing of ILI data is necessary due to the volume of data obtained in each run. There are newer analytical methods being developed and adopted in other industries that may further enhance the accurate detection and characterization of marginal signals. The industry should continue to investigate and adopt these improved analytical processes.

In addition to the guidance given in API 1163, the pipeline industry should develop guidelines for the statistical analysis of ILI data to provide acceptable options for evaluating the results of the ILI inspections and applying them correctly to IMP programs.

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APPENDICES

Appendix A

3. TOFD back scattering technique

a. Tandem probe wedge design

Tandem probes are the most suitable probes for detection and sizing of crack like flaws, which break the back surface of the test object. They are also useful for front surface breaking crack detection, but in this case, sizing capabilities are limited.

Generally, the Tandem probe can be considered as an other arrangement of dual angle beam probe, and, therefore, can be designed for a variety of refracted angles, but most commonly for high angle refracted L-waves. When an angle of incidence is equal or close to the first critical angle, several "specific" waves can be recognized in the acoustic field in a metal test object (Fig.VII-7). A strong near surface longitudinal wave **L** propagates at refracted angles of approximately 70°-76°, depending on the transducer frequency and the crystal size and shape. It is the same "longitudinal surface wave" which must propagate at the 90° refracted angle, according to the Snell's law.

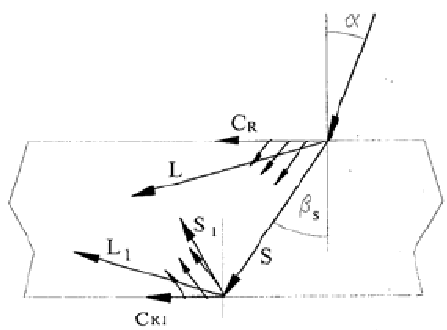


Fig.VII-7. Diagram of acoustic field in steel when an angle of incidence α is equal or close to the first critical angle.

A "creeping" wave $\mathbf{C_R}$ propagates along the front surface. This wave has a short path due to the mode conversion to "indirect" shear waves (shown in the sketch by the small arrows). A "direct" shear wave **S** propagates at the refracted angle β_s, calculated by Snell's law. When the "indirect" shear waves strike the back surface parallel to the front surface, the same set of "specific" waves is observed, only in a mirror image (marked by subscript 1). Each of these "specific" waves carries out it's own function. For example, "creeping" waves can detect very small surface breaking flaws. The longitudinal waves L and L_1, when they interact with a tip of a crack, produce diffracted waves and are very useful for crack depth sizing. Combination of S-L_2-L_3 waves provides information about crack size and serves as a flaw reconstruction tool (Fig.VII-9). Examples of not maximized signals from both shallow and deep notches, are shown in Fig.VII -8 as illustration to above mentioned statement.

a. b.

Fig.VII-8. Not maximized signals from: a) notch 0.76 mm deep, b) notch 6.0 mm deep
1. notch tip signal by L_1-diffraction wave, 2. notch trap signal by L-L wave (not shown),
3. notch face signal by S-L_2-L_3 wave, 4. notch trap signal by creeping wave.

The calculation of wedge angles for tandem probes is simple. The transmitter wedge angle is the first critical angle for a given combination of materials: wedge/test object. For the combination Plexiglas/steel, this angle is approximately 27°. The receiver wedge angle has to be 20°, according to experiments. This angle is an average of the optimum angles for diffracted and reflected waves.

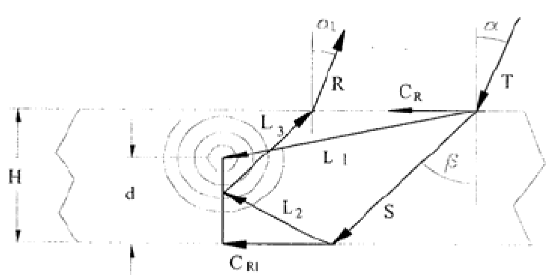


Fig.VII-9. Illustration of wave propagation with a Tandem probe can also be designed To generate above mentioned "specific" waves, in case of a dual angle beam probe, the wedges angles have to be equal to the first critical angle, but the "roof" angle should be calculated as shown in Section V.

b. "Band round waves"

Sometimes, another type of diffracted wave is used in ultrasonic NDE. When an oblique beam strikes a side-drilled hole (SDH), the rays, which are tangent to the hole surface produce "band round waves" along with a reflected wave. These waves, in turn, produce gliding diffracted waves (Fig.VII-10). This technique can be used for detection of a crack located on the hole side which is not accessible for inspection. The band round waves and gliding diffraction waves will be interrupted, and the signal, representing these waves on the screen, disappears.

This indicates the presence of a crack located in "shadow" zone. It also can be used for a hole diameter calculation by measuring the TOF of the band round wave. In this case a shear wave tandem type probe is recommended. The refracted angle of the probe should be in the region of 50°- 60°. The conceptual design of such probe is shown in Fig.VII-11.

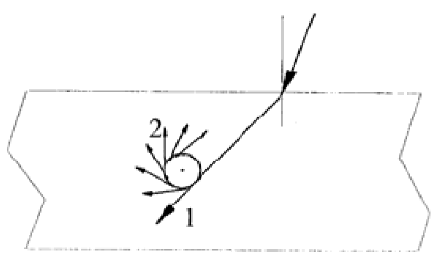


Fig.VII -10. 1) Oblique beam. 2) Gliding diffraction waves.

As any other diffracted wave, the gliding diffraction wave is weak. Its signal amplitude depends on the hole diameter. Comparing to the bulk wave reflected signal amplitude from SDH 0.50" in diameter, the gliding diffraction wave signal amplitude will be less of approximately 20-25 dB.

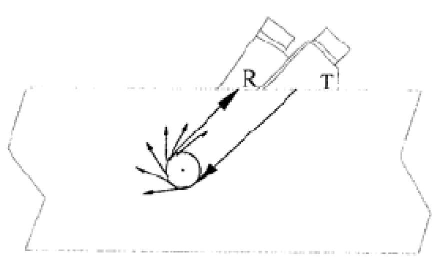


Fig.VII-11. Conceptual design of a tandem probe for detection of a crack initiated from the hole.

Appendix B

New Inspection Technologies – Phased Array UT

- Current Applications
  - BWR Core Shroud Welds H1 – H7 (BWR)
  - RPV Welds from OD Surface (BWR)
  - Dovetail Blade Attachments (Turbine-Generator)
  - Main Steam Inlet Sleeves (Turbine-Generator)
  - Nozzle Chamber to Cylinder Weld (Turbine-Generator)
  - Generator Rotor Tooth Tops (Turbine-Generator)

- Applications in Development or under Investigation
  - DM Welds from OD Surface (PWR/BWR)
  - Cast Stainless Steel Piping from OD Surface (PWR)
  - Turbine Blade Roots (Turbine-Generator)
  - Axial Entry Steeples (Turbine-Generator)
  - Tooth Tops Through Retaining Ring (Turbine-Generator)

WesDyne/Kraukramer-Japan Phased Array

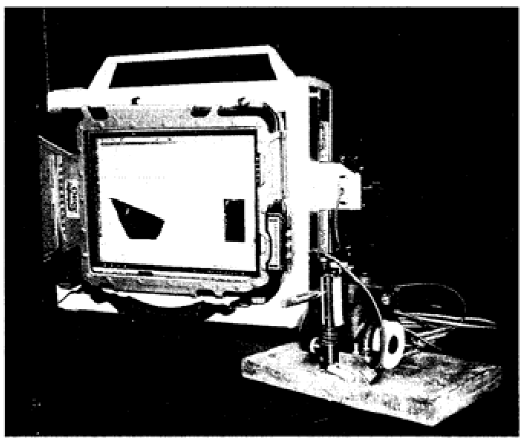
- Phased array front end built by Krautkramer-Japan
- Computer Imaging and data processing provided by WesDyne (AMDATA group)
- 32 parallel channels multiplexed to 128
- Battery operated and wireless data link options
- Automated or manual scanning supported

Appendix C

WESDYNE INTERNATIONAL

AMDATA

IntraSpect Portable Phased Array *manufactured by WesDyne AMDATA consists of a battery operated phased array acquisition system and ruggedized tablet computer running standard IntraSpect software . A wireless network is used between the phased array unit and the tablet PC to enhance flexibility. The tablet PC is a full featured computer that performs the acquisition, analysis and storage of the data. A field proven encoded manual scanner is supplied with the system for manipulation of the probe on the inspection surface. The system hardware is capable of operating up to four channels with any combination of phased array, TOFD or conventional UT probes.*



Data Acquisition Standard Features

Phased Array System Features

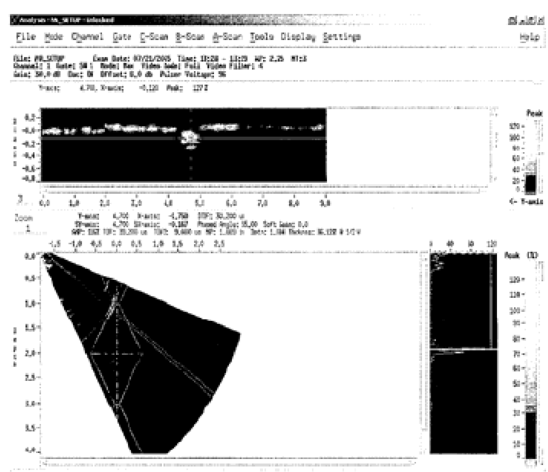
- Number of elements in system 128 Max .
- Number of elements to fire as one group 32.
- Maximum Number of focal laws 520.
- Controllable features per firing sequence.
- Delay per element step size 5 nanoseconds.
- Pulser Voltage 12V, 48V, 96V, tunable square wave.
- 4 channels of phased array or conventional ultrasonics.
- User selectable A/D rate: 20, 50, and 100 MHz.

Receiver Section Features:

- Frequency Response: 0.15 MHz to 16 MHz.
- Dynamic Range: 94 dB in 0.5 dB increments.
- Bandpass Filters: Generated from combination of low and high pass filters based on probe frequency selection.
- DAC Dynamic Range: 40 dB.

Data Analysis Standard Features

- Data Acquisition and Data Analysis on Windows XP tablet or laptop PC.
- Simultaneous C-scan, Sector–B-Scan,, and A-scan Display.
- Color Maps, Gates, and Variable Range can be altered for the graphic displays.
- Time-of-Flight and Amplitude Based Statistics Functions.
- Time-of-Flight Tip Diffraction (TOFD) Display.
- Fast Fourier Transform (FFT) Function.
- Weld Overlay Function.
- RF or Video acquisition and display modes.



Complete System:

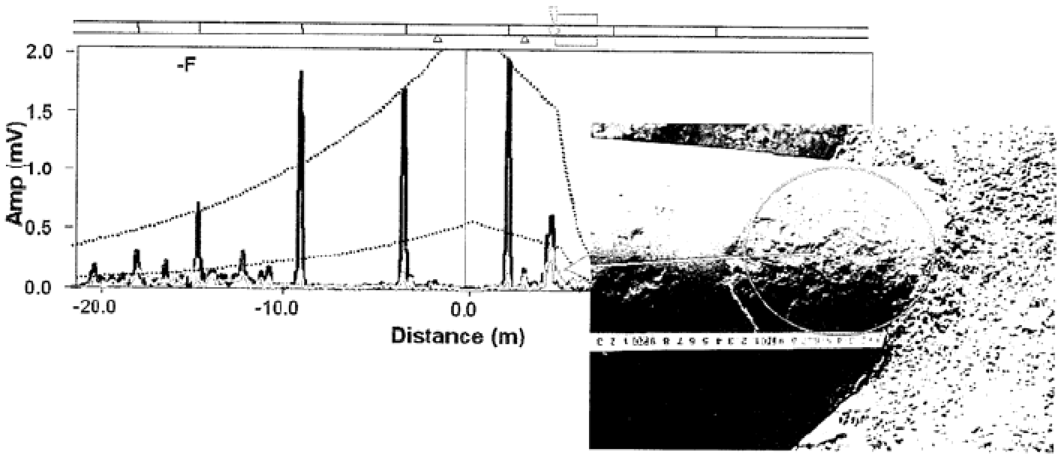
- Windows XP Tablet PC with Acquisition & Analysis software.
- 32/128 Phased Array Module, 23 lbs with 1 Battery.
- Manual magnetic wheel scanner.

WesDyne International 20 International Drive Windsor, CT 06095 (USA)	Voice: **(860) 731-1683** FAX: (860) 731-1681 e-mail: glenn.p.gagner@us.westinghouse.com Web Site: www.amdataproducts.com	

GUL WaveMaker

Long Range Guided Wave Ultrasonics

Result from (corroded) 10 inch pipe



The GUL WaveMaker is the Ultrasonic " Instrument of Choice " for the Following Applications:

- **Pipelines Coated with Bitumen, Coal Tar or other attenuating coatings**
- **Liquid Filled Piping**
- **Piping Entering into Liquid Environments (i.e., Offshore risers, etc.)**
- **Corrosion Under Insulation (CUI) in Piping systems**
- **Through-Bore Road Crossing Piping**

(More uses for Guided Wave Ultrasonics are being developed daily)

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Appendix E

Oil & Gas

EmatScan helps lower costs and raise crack-detection confidence for gas-pipeline operators

EmatScan® CD is the first in-line inspection tool to give gas pipeline operators the same crack-detection benefits and confidence levels as their liquid-pipeline counterparts.

Eliminate costly pre-inspection preparation

EmatScan CD applies Electro Magnetic Acoustic Transducer (EMAT) technology to the unique demands of in-line inspection – detecting and measuring a full range of cracking defects in gas pipelines.

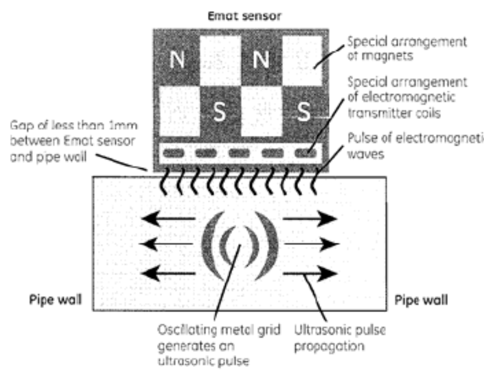
Conventional ultrasonic inspection methods require gas pipelines to be either filled with a liquid or that the tools run in a liquid batch. EmatScan CD does not require a liquid medium for its signals to reach the pipe wall. So operators no longer need to subject their gas pipelines to costly pre-inspection preparation or contamination by foreign liquids in order to obtain accurate inspection data.

Another of EmatScan CD's strengths is its ability to detect even sub-critical SCC. This capability gives operators the advanced warning essential for the initiation of effective SCC management programs – without the high costs and loss of production associated with the common (yet less efficient and statistically inferior) method of hydrostatic testing.

Crack detection capabilities

EmatScan CD is ideally suited to the detection of:

- SCC colonies
- Sub-critical SCC
- Longitudinal fatigue cracks, toe cracks
- Hook cracks
- Cracks in or adjacent to the long seam weld
- Lack-of-fusion cracks



Oil & Gas

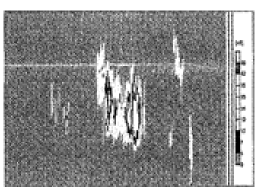
New level of data quality for gas-pipeline inspections

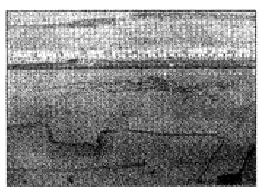
EmatScan CD provides gas pipeline operators with affordable, high-resolution inspection results – detecting cracks as short as 30 mm and as shallow as 1 mm.

The amount and detail of data provided will help operators enhance pipeline safety and decision-making confidence, while reducing overall costs by avoiding hydrostatic testing and eliminating unnecessary exploratory digs.

Key Features

- Specifically designed for gas pipelines
- Runs without a liquid batch
- Lower cost than liquid-batching techniques
- Reliable defect detection, location and sizing
- Proven reporting techniques and software capabilities
- More efficient, economical and statistically superior alternative to hydrostatic testing
- Minimal disruption to pipeline operation
- Data accuracy enables isolation of critical defects for dig and repair activities
- Allows monitoring and growth forecasting for sub-critical defects
- Improves SCC risk management and mitigation activities





The visualization in the B-Scan demonstrates that the SCC was clearly detected. The red area is echo from the defect.

Contact

For more information on EmatScan CD, contact your GE Energy representative or visit www.gepower.com/pii

imagination at work

Operating Parameters

Property	Specification
Range	100 km*
Max. Speed	2 m/s
Max. Pressure	120 bar
Temperature	10-50°C
Min. Bend Radius	3 D 90°**
Consecutive Bend Passing	1 m of straight pipe required between two bends
Min. ID in Straight Pipe	823 mm in round 777 mm in oval
Min. ID in Bend	823 mm
Tool Length	6.4 m
Tool Weight	4500 kg

*Longer range on request **1.5 D available on request

Light-coating Measurement Capabilities

Radial cracks with longitudinal orientation, longitudinal notches and gouging	In plate material, Min. length 30 mm	In longitudinal weld area, Min. length 30 mm
Min. crack depth at POD* 85%	1 mm	2 mm
Depth grouping at 85% confidence	< 2 mm 2-5 mm > 5 mm	2-5 mm > 5 mm
Length sizing accuracy at 85% confidence, defect length ≤ 100 mm	±10 mm at 2 m/s	±10 mm at 2 m/s
Length sizing accuracy at 85% confidence, defect length > 100 mm	±10% at 2 m/s	±10% at 2 m/s
Deviation from longitudinal orientation	±10°	±10°
Internal/external discrimination	yes	yes

*Probability of Detection

Heavy-coating Measurement Capabilities

Radial cracks with longitudinal orientation, longitudinal notches and gouging	In plate material, Min. length 50 mm	In longitudinal weld area, Min. length 50 mm
Min. crack depth at POD 85%	2 mm	2 mm
Depth grouping at 85% confidence	2-5 mm > 5 mm	2-5 mm > 5 mm
Length sizing accuracy at 85% confidence, defect length ≤ 100 mm	±10 mm at 2 m/s	±10 mm at 2 m/s
Length sizing accuracy at 85% confidence, defect length > 100 mm	±10% at 2 m/s	±10% at 2 m/s
Deviation from longitudinal orientation	±10°	±10°
Internal/external discrimination	yes	yes

Appendix F

Summary of Research for Mechanical Damage That Included Battelle

Start	End	Contractor(s)	Sponsor	Outcomes
Oct 1994	May 1996	Battelle, SwRI	GRI	Feasibility of MFL to better characterize mechanical damage.
Sep 1996	Dec 1999	Battelle, SwRI, Iowa State	DOT	Magnetic properties of pipeline steels an Dual magnetization. Non linear harmonics and neural networks.
May 2000	Jun 2003	Battelle, SwRI	GTI / DOT	Validation of decoupling and evaluation of circumferential MFL. Nonlinear harmonics and mechanical assessment.
Sep 2001	Sep 2003	Tuboscope	GTI	Technology transfer
Sep 2003	Mar 2005	Battelle	DOT / PRCI	Design of a dual magnetization tool. Technology demonstration
May 2006	May 2008	PRCI	DOT / PRCI	Testing of a tool in an operating pipeline

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NOTES.